An empirical study: Usage of the Unified Modeling Language in the Bachelor of Science and Master of Science degree programs at California State University, San Bernardino

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AN EMPIRICAL STUDY: USAGE OF THE UNIFIED MODELING LANGUAGE IN THE BACHELOR OF SCIENCE AND MASTER OF SCIENCE DEGREE PROGRAMS AT CALIFORNIA STATE UNIVERSITY, SAN BERNARDINO

A Thesis

Presented to the

Faculty of

California State University

San Bernardino

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

in

Computer Science

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by

Cynthia Patrice Farquhar

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ABSTRACT

The Unified Modeling Language (UML) became part of the curriculum in the Department of Computer Science at California State University, San Bernardino (CSUSB) in September 1997. The intent was to integrate the object-oriented paradigm in the undergraduate courses. Subsequently, this use has shifted to the graduate level courses. This study is a continuation of the research that Dr. Botting began. [5] His findings were presented to the National Science Foundation in the fall of 2003. The purpose of this thesis is: 1) to determine what the students know about the UML, 2) to reveal if the students were using UML, 3) to clarify how the students used the UML. Of the 389 undergraduate students and 154 graduate students enrolled in the university in the spring of 2004, 35 upper division undergraduates (9%) and 44 graduates (29%) completed the survey. All of the undergraduates surveyed know what the UML is compared to 96% of the graduates. The usage varied between using the UML as a blueprint (or architecture), sketch, programming language and required documentation.

The analysis of the data maps the adoption of the UML

at CSUSB. It shows that students used the UML to some degree as a blueprint 76% of the time, as a sketch 78% of the time, as a programming language 38% of the time, and for required documentation 83% of the time. This does not mean that a student used the UML one way exclusive of another.

The major benefit from this study is that it shows how UML is being used at CSUSB. This gives some insight to the faculty as to the direction of future teaching of UML. Additionally, the results give a hint to the business community on how the UML is being used. Although CSUSB is an educational establishment, it seems likely, on the basis of this research, that UML will continue to play a part of software development in the future.

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You are the wind beneath my wings: words of a popular song that represent my thought to the following people:

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CHAPTER ONE

INTRODUCTION

"Software engineering is the sub-discipline of computer science that concerns itself with the entire process of software creation." [17] One of the biggest challenges in developing software is communication between the parties involved. Time is money. Repeatedly discussing software during its creation takes time, this in turn costs money. However, with many teams of people involved in the creation process, this communication must happen to remove the possibility for error. Additionally, the more people involved in a project, the more time is spent on communication. [5] In the computer science arena, there was a movement underway that would aid with the need for extensive communication. There was a desire to standardize the language unifying "the many threads and incarnations of the Knowledge Revolution." [4] "Unification creates a single, consistent system from the most prominent methods within the industry." [3] The OMG (Object Management Group) decided to accept and standardize the method and language for creating and depicting software development plans.

standardization allowed for unification and aided in minimizing confusion by providing a means to visually see the interactions and relationships in a program. CSUSB followed in the same direction. In his report, Dr. Concepcion states "in September 1997, the Department of Computer Science, CSUSB, undertook the ROOT (Refashioning Object-Oriented Technology/Teaching) Project in partnership with Rational Software through the SEED (Software Engineering for Educational Development) program. [8] Five undergraduate classes were targeted to use object-oriented analysis and design, using the UML. [8] Since 1997, the UML has been integrated in the graduate level courses. Because the UML has been the standard for over six years, the question at hand was how well it has been accepted and how it has been used at CSUSB.

1.1 History

The Unified Modeling Language is a language unique to software development. In particular, it is a language that is used for "specifying, visualizing, constructing, and documenting artifacts of software systems, as well as for business modeling and other non-software systems." [2]

As stated earlier, it is to the software engineer what blueprints are to the architects and engineers. It is not:

❖ A visual programming language, but a visual modeling language.

❖ A tool, but a language.

❖ A process, but enables processes. [4]

It is:

❖ A general-purpose modeling language.

❖ A broadly applicable modeling language.

❖ A tool-supported modeling language.

❖ An industry-standardized modeling language. [4]

The use of the UML is fundamentally for communication [11] within the software development process. It can also be used for code generation.

1.2 Diagrams

The basis of the UML requires using different types of predetermined diagrams. Following are types of diagrams used: use case, class (object), interaction (sequence and collaboration), state, activity, and physical (deployment and component).

The use case diagram is one of the most widely used diagrams. "Use case diagrams describe the functionality of a system and users of the system." [3] Use case diagrams use an actor to model the user's role with respect to the system. Actors perform what the use case illustrates. An actor might carry out multiple use cases. Similarly, use cases could have many actors. [12] Actors can be any entity "that needs some information from the current system." [12]

The second most used diagram, due to its broad "range of modeling concepts," [12] is the class diagram. "Class diagrams describe the static structure of a system, or how it is structured rather than how it behaves." [3] Each class diagram consists of: (1) name, (2) structure, and (3) behavior. The fundamental ideas associated with the class diagrams that are used most include: (1) objects and (2) relationships. Object diagrams display a picture of the objects at a specific time. [12] Relationships that exist between the objects can be broken down to show associations and subtypes.

Fowler states that there are "three perspectives you can use in drawing class diagrams."[12] These include: (1) conceptual, (2) specification, (3) implementation. To show how concepts interrelate, one would use the conceptual perspective. The primary use for specification is when "the interfaces of the software, not the implementation" [12] are examined. Implementation demonstrates how the program is set to perform.

"Sequence diagrams describe interactions among classes."[3] They contain the following:

1) class roles (how objects behave within interaction)
2) lifelines (longevity of object)
3) activations (time performing operation)
4) messages (communication between objects) [3]

State diagrams are used to show "the behavior of an object in reaction to an event." [15] In other words, when something happens to a class, the state diagram shows how the state of the class changes based on the external stimuli. A state could be active, inactive or in transition depending on the particular situation.

Activity diagrams depict the class behavior in response to internal processing. [3] They are good for modeling algorithms and procedures. Deployment diagrams show "the assignment of concrete software artifacts to computational nodes." [15]

Deployment diagrams show how resources are being utilized. These diagrams provide a total view of the system. The resources shown in a deployment diagram include computers and printers.

Component diagrams show how the system gets implemented. These diagrams include all components and their individual relationships. "Components are classes that define development-time and run-time physical objects." [3] They are much like a class diagram except a component diagram emphasizes "that the interfaces are important, and it is modular, self-contained and replaceable." [15]

1.3 Versions

There are many versions of the UML. Initially, it began as the result of the combined work of Booch (Ada method) and Rumbaugh (OMT). This version was 0.8. When Jacobson (Objectory) joined forces with Booch and Rumbaugh and version 0.9 was released. At this juncture, the name Unified Modeling Language was adopted.

The UML underwent two main changes and some minor changes. The major changes happened between UML 1.0 to 1.1 and UML 1.2 to 1.3. These changes included a broader scope for the class diagram, a more definitive understanding of the {complete} and {frozen} restraint and the term "role".

From UML 1.2 to 1.3 the changes included relationships in the use case diagrams and semantics of the activity diagrams. The use case diagrams in UML 1.3 contain <<include>> (which replaced <<uses>>), <<extend>>, and use case generalization. [12] The fork and join replaced the synchronization bar in activity diagrams. [12] Conditional behavior was noted by the diamond-shaped decision activity. [12] The profile and artifact appeared in UML 1.4. Additionally, the symbol "~" emerged as a means "to handle Java's *package* visibility." [12]

The most modifications of the UML took place in UML 2.0 in 2004. New diagrams emerged (object and package diagrams). Name changes to existing diagrams occurred (collaboration to communication diagrams). New diagram types (interaction overview diagrams, timing diagrams, and composite structure diagrams) surfaced. The class diagram underwent some changes that included some new keywords. [10] Sequence diagrams now managed behaviors. Activity diagrams no longer needed to adhere to the matching forks and joins as in UML 1.

CHAPTER TWO

PURPOSE OF THE STUDY

The object oriented (OO) paradigm using the UML came to CSUSB because of the ROOT (Refashioning Object-Oriented Technology Teaching) project [9] in 1997. This project was a joint effort of the Department of Computer Science at CSUSB and Rational Software through the Software Engineering for Educational Development (SEED) Partnership. [9] The need for this project arose from the demands of the software industry. This industry needed "computer science graduates with training and education in the object-oriented paradigm." [9] This project was accomplished by integrating the UML into undergraduate classes.

The purpose of this study was: 1) to determine what students knew about UML 2) to reveal if the students were using UML, and 3) to clarify how the students used UML. By determining how the UML was being used, the study also differentiated if usage was due to personal preference or due to course requirements from the faculty. Additionally, to determine whether there had been an increase in usage of the UML over the last seven years, past theses and projects were reviewed. Faculty responses to the questionnaire were also documented. Their responses validated how they used the UML.

Ritu Agarwal and Atish Sinha published their report of a similar type study that was "aimed at assessing the usability of UML." [1] The study dealt specifically with techniques and basic usability of the UML. The population that was surveyed included developers with prior training in the UML. The difference with their study and this thesis lies in the fact that professionals in the computer science industry rather than students were surveyed. Students typically do not have the same exposure and experience to the UML as do professionals. Surveying students paints a clear picture of how the UML is used at the educational level.

Martin Fowler, in his speech at the UML Conference in San Francisco, challenged academia to determine how the UML was being used on college campuses. [11] His concern with this issued was encouragement to continue with this research, especially since his classifications of the UML are seminal. Craig Larman, in his book <u>Applying UML and Patterns, An Introduction to Object-Oriented Analysis and Design and Iterative Development</u>, uses this same classifications as Fowler. Larman used three of the four examples: blueprint, sketch, and programming language. [15] Required documentation is a usage that Fowler added to his challenge to academia to find out if students were using the UML due to requirements rather than personal preference. Using the UML for required documentation indicated that the user did not have a choice. The survey conducted as part of this paper identifies this choice. Fowler's challenge to academia substantiated the need for this research.

CHAPTER THREE

METHODOLOGY OF RESEARCH

The plan of attack took on three phases. In the first phase, students that were currently enrolled in a computer science class at CSUSB were surveyed. Phase 2 involved investigating past computer science master's projects. The final phase surveyed the faculty members. Gathering information from all three groups was necessary to realize the full scope of the use of the UML in the computer science department.

3.1 Student Surveys

The survey was developed via a pilot survey. Before distributing this questionnaire to the students, permission from the Institution Review Board (IRB) was needed. Approval for distribution of the pilot questionnaire was given February 20, 2004, and was given an Exempt Review IRB #03083 (Appendix G). After receiving IRB approval, the pilot questionnaire was distributed to three computer science classes to determine the base knowledge and understanding of the UML. The courses necessary for a BS degree in Computer Science at CSUSB follows a logical flow. (Appendix I) Two undergraduate classes and one graduate class participated with the pilot questionnaire: CSCI 330, CSCI 455, and CSCI 599. These classes were chosen because they follow CSCI 201 and 202 (Computer Science I and II) in the computer science curriculum. (Appendix I) These two classes are the student's first exposure to the UML. After completing CSCI 202, CSCI 330, Data Structures, is one of the next classes to be taken. It includes more UML. This class deals with "abstract data structures including lists, stacks, queues and trees; their storage allocation and associated application algorithms." [7] CSCI 455, Software Engineering, follows CSCI 330. Software Engineering is a class that studies "advanced techniques and technology used to produce large software systems." [7] It is one of the last core classes taken for a bachelor's degree in computer science. It uses a lot of UML. CSCI 599, Foundations of Software Systems, is a graduate class that has the UML integrated in the course work. This class must be taken as an elective for those students who did not fulfill the data structure and operating system requirements. Specifically, in this class, students learn the "software development process which includes software life-cycles, software techniques and technologies used to produce large software systems; operating systems including processes, input/output, memory management, and file systems." [7] Answers to this survey were analyzed and used to refine the questionnaire for the actual survey.

Next, the final questionnaire was created and needed approval from the IRB for a protocol change. This was approved on May 14, 20004 (Appendix H). The final questionnaire was subsequently distributed to three undergraduate classes (CSCI 330, CSCI 401, and CSCI 460) and three graduate classes (CSCI 620, CSCI 630, and CSCI 660). Once again, the classes that were chosen to participate with the survey followed the appearance of the UML in the curriculum for computer science. CSCI 330, Data Structures, was chosen for a second time for the same reason as stated previously. CSCI 401, Contemporary Computer Architecture, is a core class that follows CSCI 310 and CSCI 313, Digital Logic and Machine Organization. This class requires CSCI 201 and 202. Contemporary Computer Architecture is a class dealing with "design methodology; processor units and control units of von Neumann computer architectures; RISC architectures, including pipelining and parallel-processing." [7] CSCI 460, Operating Systems, follows CSCI 330 and CSCI 313. The Operating Systems class is "an overview of operating systems [that deals with] principles of resource management and control. Multiprogramming, distributed systems and multiprocessor systems [are] included." [7] The graduate classes chosen were: CSCI 620, Programming Languages, CSCI 630, Theory of Algorithms and Their Analysis, and CSCI 660, Operating System Concepts and Theory. As with previous selections, these classes were chosen due to their standing in the requirements for a Master's Degree in Computer Science. While both CSCI 630 and CSCI 660 are required classes, CSCI 620 is an elective class. This combination of elective and required classes gave good coverage of the whole student population.

3.2 Master's Projects

In order to determine the usage of the UML throughout the last 7 years, past Master's projects were reviewed. Sixty-three research papers were reviewed. This represents all of the Master's projects that were found in the Computer Science office at the time of the survey. The goal was to document any reference or usage of the UML over the last seven years. Theses that dealt with research only were not included in this survey, only projects that had programs.

3.3 Faculty

Seventeen questionnaires were distributed to the faculty members that were noted on the Computer Science web site at CSUSB. Responses to the questionnaire about using the UML were documented. Of the 17 instructors that were targeted, four of them were part-time lecturers, one was a fall lecturer, and 12 were tenure-track computer science faculty members. There was no differentiation between the full time faculty members and the others surveyed. The part-time lecturers typically teach classes that fall under the umbrella of the Computer Science Department, yet are not required classes for a bachelor's degree in Computer Science. The fall lecturer was a seasonal instructor, not a full time faculty member. The twelve tenure-track faculty members teach the required computer science classes for a degree in Computer Science.

CHAPTER FOUR

STATISTICAL RESULTS

4.1 Survey Results

The pilot questionnaire was the first part of the study that was reviewed. The questionnaire was designed to determine how many students had even heard of the UML. The following Table 1 summarizes the findings:

Table 1. Pilot Questionnaire Results

CLASS	DISTRIBUTED	HEARD OF UML	NOT HEARD OF UML
Computer Science 330	14	12	2
Computer Science 455	30	30	0
Computer Science 599	10	10	0

Out of the 54 questionnaires distributed, only two students (or 3%) had not heard of the UML. This means that 97% had heard of the UML. The two students that had not heard of the UML were in CSCI 330 Data Structures. The following graph (Figure 1) shows the distribution.

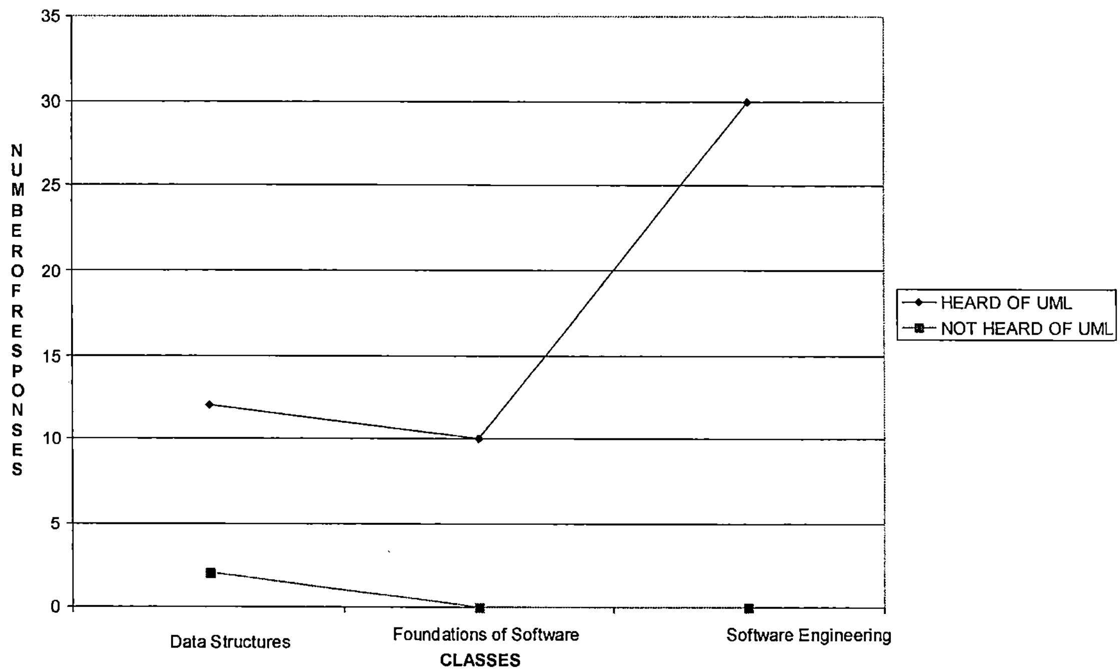


Figure 1. Pilot Questionnaire #2

After reviewing these results, how the students used the UML was of interest. (Please note that four students did not answer this question.) Clearly, in the undergraduate classes, the UML was being used as a blueprint. However, in CSCI 599, the UML was primarily being used for required documentation. The following table summarizes the findings:

Table 2. Pilot Questionnaire Usage Results

CLASS	SKETCH	BLUEPRINT	PROGRAM LANGUAGE	REQUIRED DOCUMENTATION
Computer Science 330	3	5	2	0
Computer Science 455	7	14	1	8
Computer Science 599	2	3	1	4

The test for associations used the χ^2 formula:

$$\chi^2 = \frac{(\text{Observed} - \text{Expected})^2}{\text{Expected}} \qquad \text{Equation (1)}$$

"Chi square derives a representation of the null hypothesis—that all things being equal scenario by the following. The expected frequency in each cell is the product of that cell's row total multiplied by that cell's column total, divided by the sum total of all observations [9]." A test for an association between the answer from question #4 (I use the UML regularly for my software development.) and #5 (I use the UML as: 1) a sketch, 2) a blueprint, 3) a programming language, 4) required documentation) was done. This was for the responses received from the students in CSCI 455. The results were found to be: χ^2=8.05 with significance at the 1 degree of freedom. This association is unlikely to be a random effect.

Table 3. Computer Science 455: Software Engineering

Responses	Agree	Disagree	Totals
Blueprint	12 (exp 9)	2 (exp 5)	14
Required Documentation	1 (exp 4)	6 (exp 3)	7
Totals	13	8	21

For χ^2 data used for CSCI 330 and CSCI 599 see Tables 4 and 5.

Table 4. Computer Science 330: Data Structures

Responses	Agree	Disagree	Totals
Blueprint	3 (exp 4)	2 (exp 1)	5
Programming Language	2 (exp 1)	0 (exp 1)	2
Totals	5	2	7

χ^2 for CSCI 599 was calculated to be 2.5 with 1 degree of freedom. For CSCI 330, χ^2 was calculated to be 3.25 with one degree of freedom.

"Blueprint" and "a programming language" were used for the summary of CSCI 330 because no answers reflected required documentation.

Table 5. Computer Science 599: Foundations of Software Systems

Responses	Agree	Disagree	Totals
A blueprint	2 (exp 1)	1 (exp 2)	3
Required Documentation	1 (exp 2)	3 (exp 2)	4
Totals	3	4	7

The students in CSCI 599 were split on the issue. Five students stated that they used the UML regularly. Five students did not. Of the students that used UML regularly, two used it as a blueprint, one as a programming language, one as a sketch and one for required documentation. Three of the five students that did not use the UML regularly use it for required documentation. Of the other two, one used it for a blueprint; one used it as a sketch. See Table 6 below.

Table 6. Computer Science 599: Foundations of Software Systems Usage Results

	Blueprint	Programming Language	Sketch	Required Documentation
Used UML Regularly	2	1	1	1
Did Not Use UML Regularly	1	0	1	3

In CSCI 330, 12 responses were recorded. Seven students claimed that they used the UML regularly, whereas five did not. The table below explains the distribution.

Table 7. Computer Science 330: Data Structure Usage Results

	Blueprint	Programming Language	Sketch	Required Documentation
Used UML Regularly	4	2	1	0
Did Not Use UML Regularly	3	0	2	0

The last question on the survey was open ended to get any feedback from the students. Some of the comments were quite interesting and are listed in Appendix A. The final questionnaire was distributed to the following three undergraduate classes:

1) Computer Architecture (CSCI 401)
2) Data Structures (CSCI 330)
3) Operating Systems (CSCI 460).

And the following graduate classes:

1) Programming Languages (CSCI 620)
2) Theory of Algorithm Analysis (CSCI 630)
3) Operating Systems (CSCI 660).

It was important to have a population that was a good distribution of both undergraduate students and graduate students. Having a larger number of students from either class could have adversely affected the resulting survey.

The following graph shows the mix of students that returned surveys.

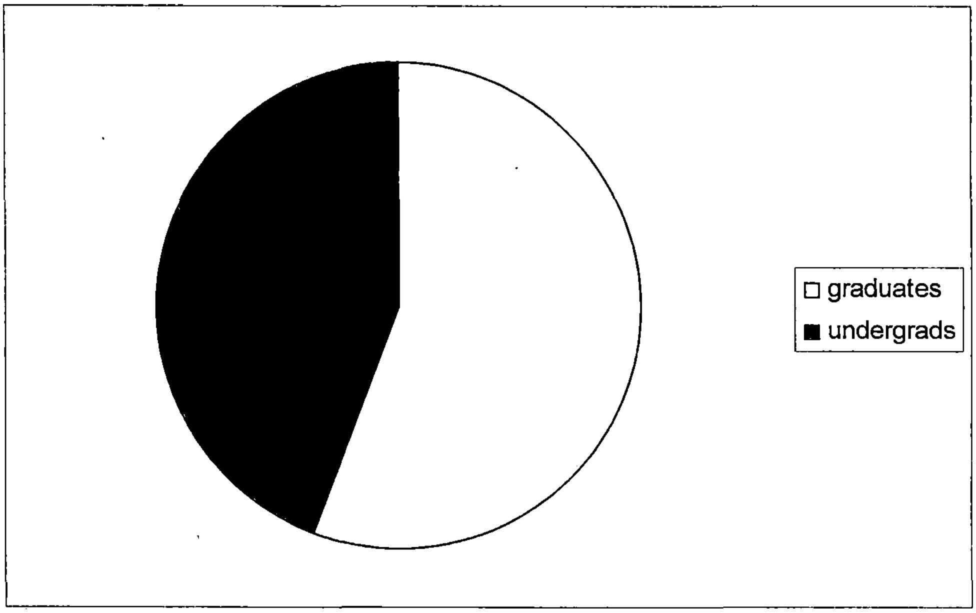


Figure 2. Total Population Surveyed

To prevent duplication of survey results, students were asked to simply write, "Already taken" across the top of the questionnaire if they had already completed on in any other course. This indicated that the student's answers were already taken into consideration and not that the students declined to participate in the survey. This also minimized the possibility of dual answers being submitted and indicated when the population had been saturated.

Once there were more surveys with "Already taken" written across the top of the survey than completed surveys, most of the students in the computer science department had been reached. The following chart displays this idea clearly.

Table 8. Completed Questionnaires

CLASS	PASSED OUT	COMPLETED	ALREADY TAKEN
Computer Science 330	10	10	0
Computer Science 401	11	4	7
Computer Science 660	27	26	1
Computer Science 620	24	24	0
Computer Science 630	22	4	18
Computer Science 660	24	24	0

After determining that the majority of the population had been reached, and that the population was a good cross section of undergraduate students and graduate students, statistical analysis of the data began. The analysis began with question #2, "I have heard of the UML." Table 8 shows the results.

Table 9. Questionnaire Results/Heard

Class	HEARD OF UML	NOT HEARD UML
Computer Science 401	4	0
Computer Science 330	10	0
Computer Science 460	27	0
Computer Science 620	9	0
Computer Science 630	4	2
Computer Science 660	24	0
TOTALS	78	2

Once it was determined that most of the population surveyed had at least heard of the UML, the number of students that use the UML on a regular basis for program development was calculated. (Appendix A, question #4) The numbers were close, but the result was not as expected. Thirty-four (34) of the 74 students that had answered this particular question responded with a positive answer.

That means that 46% used the UML regularly for software development. So, 54% did not use the UML on a regular basis. There was no apparent difference between the percentage of graduates and undergraduates that use the UML regularly. In other words, 46% of the undergraduate and 46% of the graduate students used the UML regularly. Conversely, 54% of both the undergraduate and graduate students did not use the UML regularly. A comparison was made for an association using Equation (1) between question 4 and question 5. (Appendix A)

Table 10. Usage Table

	AGREE	DISAGREE	TOTALS
OCCASSIONALLY	13 10(exp)	22 25(exp)	35
NEVER	3 0(exp)	17 14(exp)	20
TOTALS	16	39	55

Table 9 shows the figures that were used. χ^2 was calculated to be 2.1 (with 1 degree of freedom.) This association is unlikely to be a random effect, given that $P<\chi^2 \cong 0.15$, or a z-score of 1.

At the UML Conference in San Francisco, Martin Fowler questioned how the UML was actually being used. This concept was added to the survey. The following table tells the story:

Table 11. Total Usage Results

	Always	Often	Occasionally	Never	Totals
Sketch	5 (6%)	16 (21%)	39 (51%)	17 (22%)	77
Blueprint	5 (6%)	18 (23%)	25 (32%)	29 (38%)	77
Programming Language	3 (4%)	10 (13%)	16 (21%)	47 (62%)	76
Required Documentation	9 (12%)	25 (33%)	29 (38%)	13 (17%)	76
Totals (responses)	22	69	109	106	306

This means that a sketch is used always about 6% of the time, but combining "often" and "occasionally" it is used 72% of the time. The most startling result is the fact that 62% of the time it is never used as a programming language.

Appendix B shows the mean, mode and median of each question on the final survey. "Strongly agree" was given a value of 1. "Agree" was given a value of 2. "Disagree" was given a value of 3. "Strongly disagree" was given a value of 4. The chart shows that most of the time the mean, average, was very close to the mode, or the answer that was most often chosen. Question number 7 states: "The UML is difficult to understand." The mean numerical answer to this question was 2.9, meaning that is was between agree (2) and disagree (3). Question number 9 states: "I find the UML to be confusing." The mean numerical answer to this question was 2.8. This indicates that most of the student's answers are more in disagreement with the statement. Resulting numerical values can be seen in Appendix E.

When comparing the number of undergraduate students that use the UML regularly for software development to the number of graduate students that use the UML, the numbers were close. Sixteen of the 35 undergraduate students surveyed use the UML on a regular basis for software development. This number is slightly lower than the 19 graduate students that use the UML in the same manner.

4.2 Master's Thesis and Projects

Of the sixty-three documents that were reviewed, forty-four had a mention of the UML or used UML notation. One of the earliest projects that actually used the UML was that of Alka Nand in 1997. In this paper class diagrams were used several times. [16] Sumit Imsuksri also used some UML in his paper. He even called it "Universal Modeling Language."[13] His paper was written in 2002.

Following is a table that indicates the frequency of the diagrams that were used in theses and projects.

Table 12. Diagram Usage in Thesis/Projects

	Use case	Class	Interaction	State/ Activity	Deployment
Thesis/ Projects	22	17	0	1	1

By year, the following table shows the increase usage of the UML in Master's projects.

Table 13. Usage in Master's Projects

Year	Uses UML	Use Case Diagram	Class Diagram
1997	1	1	0
1998	1	1	0
1999	1	1	0
2000	2	0	2
2001	5	1	4
2002	9	5	4
2003	13	7	6
2004	16	10	6

4.3 Faculty

The same questionnaire that was given to the students was given to the faculty with a cover letter encouraging any additional comments. Only five questionnaires from faculty members were returned. Of the five that were received, one had never heard of UML. From the four that have heard of the UML, only one was able to correctly identify that the UML was not a method for software development and that it was, in fact, a language. Two faculty members actually use the UML regularly for software development. Regarding the question about using the UML as a sketch, three members only use it occasionally. One member uses it always. There were no additional comments about the UML received despite an encouragement to do so.

CHAPTER FIVE

CONCLUSION

"The survey was designed to find out how well students at CSUSB were learning one small part of the curriculum." [6] This is the first small step in the direction of answering the larger question of UML's future. Not all responses to all questions were noted. Important items were discussed within the chapter identified. Resulting data from the survey has been reported and displayed in graphical form. The target was narrow. It included only students enrolled in Computer Science classes. There were 389 undergraduates and 154 graduates registered at the time the survey was conducted. The procedure was simple. The results are limited only to the use of the UML at CSUSB. The content of the surveys asked pertinent questions to the usage of the UML. The right group of people was asked. "The results may not apply to experienced practitioners or students in other programs, or to other notations, languages, and methods. Further research is needed to establish how the UML is being applied in practice and what it's future will be." [6]

Kitchenham discusses data validation and policies for handling incomplete questionnaires. [14] In her paper, she states that even when some surveys are incomplete, sample statistical analysis can be done as well as mean values can be calculated. The number of incomplete questionnaires was so insignificant that all papers were accepted. In the pilot questionnaire, some questions were found to possibly have two answers. To remedy this, the final questionnaire removed any and all possibilities of this happening.

The population that returned the surveys demonstrated a mix of undergraduates and graduates. Based on the number of surveys that were returned marked "Already taken," the majority of the desired population of computer science students was reached. Of this population, almost all had heard of the UML.

The pilot questionnaire proved to be a valuable tool and provided insight for the formulation of the final questionnaire. In particular, the responses to question #5 were somewhat mixed. [Appendix A] Some students marked more than one response. Some students put numbers beside the answers. The final questionnaire split the responses into four different questions. As stated previously, based on the responses (see Chart 8), 62% never use the UML as a programming language. This is significant. Between 50% and 72% of the responses stated that the use of the UML as a sketch, blueprint, and for required documentation was often and occasionally.

Fowler states in his book [12] that the UML is a modeling language, not a method. Of the 85 questionnaires that were returned, only five knew this fact. This opens the door for future study on how students and faculty define methods and languages.

Of the master's project reports that were reviewed, over 74% had some mention of the UML. Most commonly used diagrams were the use case diagram and the class diagram. The information reported in Table 12, clearly shows that the usage of the UML has increased since 1997.

The faculty allowed access to their classes for the purpose of distributing the survey. Yet, at the same time, there were not many questionnaires returned from the faculty. The busy schedules and workload of faculty members might have something to do with this. The number of faculty members that returned the survey was 30%. Two of the faculty surveyed actually uses the UML with any regularity (40%). This could be an area of concern.

In closing, the usage of the UML has been increasing in a positive direction. The knowledge of UML is definitely rising. The usage, based on the answers of survey, indicate that the UML is being used at CSUSB as a sketch and for required documentation.

Based on the information already provided, the UML is becoming more of an accepted "modeling language for specifying, visualizing, constructing, and documenting the artifacts of a system-intensive process." [4] These results may not apply to experienced practitioners or students in other programs, or to other notations, languages, and methods. Further research is needed to establish how the UML is being applied in practice and what it's future will be. The Computer Science Department should carry out a similar survey of its alumni.

In his speech at the UML conference in San Francisco, Martin Fowler challenged the audience with the question of finding out how the UML is being used. [8] This particular study had already begun. Because so little time has transpired since Fowler's challenge to academia, no student surveys similar to this one were found. Comparable surveys on other university campuses would be helpful. Since beginning this paper, UML 2.0 has been developed and released. Further research in response to the new version would certainly be appropriate. The reference manual for UML 2.0 includes over 600 pages of documentation. [11] The size of the manual could be a deterrent to some students and developers. This definitely leaves the door open for further research on the subject.

APPENDIX A

DRAFT PILOT QUESTIONNAIRE

This is an anonymous and voluntary survey. It has no effect on your grade. I am gathering information for my thesis about the usage of the UML. If you do not wish to participate, just return this blank form. Only statistical aggregated results will be reported. Do not add any names, numbers, or other identifying information on this sheet. This questionnaire has been reviewed and approved by the Institutional Review Board (#03083)

QUESTIONS ABOUT UML

1. What is your current classification?
   1) Undergraduate
   2) Graduate

2. I have heard of the UML.
   1) Yes
   2) No; Please skip the rest of the questionnaire.

3. The UML is a method for software development.

Strongly agree…somewhat agree…somewhat disagree…strongly disagree

4. I use the UML regularly for my software development.

Strongly agree…agree…disagree…strongly disagree

5. I use it as:

   1) A sketch
   2) A blueprint
   3) A programming language
   4) Required documentation

6. The UML is difficult to understand.

Strongly agree…agree..disagree…strongly disagree

7. An actor is part of the UML.

Strongly agree…agree…disagree…strongly disagree

8. I find the UML to be confusing.

Strongly agree…agree…disagree…strongly disagree

9. Any other comments about the UML?

Thank you very much for your time and trouble with this survey.

APPENDIX B

QUESTIONNAIRE

This is an anonymous and voluntary survey. It has no effect on your grade. I am gathering information for my thesis about the usage of the UML. If you do not wish to participate, just return this blank form. Only statistical aggregated results will be reported. Do not add any names, numbers, or other identifying information on this sheet. This questionnaire has been reviewed and approved by the Institutional Review Board (#03083)

QUESTIONS ABOUT UML

1. What is your current classification?
    1) Undergraduate
    2) Graduate

2. I have heard of the UML
    1) Yes
    2) No; please skip the rest of the questionnaire
3. The UML is a method for software development.

Strongly agree…somewhat agree…somewhat disagree…strongly disagree

4. I use the UML regularly for my software development.

Strongly agree…agree…disagree…strongly disagree

5. I use the UML as a sketch:

    Always…often…occasionally…never

6. I use the UML as a blueprint:

    Always…often…occasionally…never

7. The UML is difficult to understand.

    Strongly agree…agree…disagree…strongly disagree

8. An actor is part of the UML.

    Strongly agree…agree…disagree…strongly disagree

9. I find the UML to be confusing.

Strongly agree…agree…disagree…strongly disagree

10. Using the UML makes it easier to produce code:

Always…often…occasionally…never

11. Use cases are a part of the UML:

Strongly agree…agree…disagree…strongly disagree

12. I use the UML as a programming language:

Always…often…occasionally…never

13. I use the UML as part of required documentation:

Always…often…occasionally…never

14. I would like to see the UML taught in greater detail at CSUSB in one specific class:

Strongly agree…agree…disagree…strongly disagree

15. Given the choice, I would not use the UML:

Strongly agree…agree…disagree…strongly disagree

16. Any other comments about the UML?

Thank you very much for your time and trouble with this survey.

APPENDIX C

PILOT QUESTIONNAIRE COMMENTS BY CLASS

Computer Science 330: Data Structures

1. Modeling language.
2. It is very useful to develop programs.

Computer Science 455: Software Engineering

1. OO can be counter-intuitive, not necessarily a problem with UML.
2. UML is a great way to set up before coding.
3. It takes some time to understand.
4. Complemented with other things it is good.
5. I believe that [the] UML will exist outside of computer science eventually. Saying the UML is exclusive to software development is a bit narrow.
6. We just need more software to use UML with other
7. Hard to learn, but when learned, it will [be] easy for using.
8. Been using [the] UML for 1½ years. I think it is absolutely necessary for "oop!"
9. It avoid[s] confusion of speaking language.
10. UML is very useful.
11. UML is easy to lean and understand.
12. I think we should use it more in class.
13. Few teachers emphasize it.
14. Want UML 2.0.
15. It's not too hard to learn, at least what I've seen.

Computer Science 599: Foundations of Software Systems

1. I think user diagram and state diagram and physical diagram is hard to draw.
2. Great visual outline in software development.
3. No, but window application for UML is needed in CSUSB.
4. It is not taught much in 201, 202, 330. I haven't learned it well.
5. I'm still learning.

APPENDIX D

FINAL SURVEY COMMENTS

Computer Science 330	Not too familiar with it…sorry It is a great way to program. I don't have much learning about UML. I think if we include UML in some class as part of the lecture, it would be more understanding. I think the whole class of UML would be boring.
Computer Science 401	UML should not replace flow charts. I HATE IT.
Computer Science 460	Good tool for software management. The best way for communication among human. Start the UML with CS201. UML is a great too for software development. I would like to see a class for it. A good idea is to mix with a lot of classes. I look forward to seeing UML becoming more than just a software engineering tool.
Computer Science 620	UML is very useful but we could not learn efficiently. It must be offered as a graduate class. UML should be taught as clearly as C++.
Computer Science 630	It's useful.
Computer Science 660	Need more UML tools (Rational Rose). I'm still learning, so, I don't know. I've heard of UML, but never used it. You need a roadmap. This is one of the best.

APPENDIX E

MEAN/MODE/MEDIAN TOTAL POPULATION
FINAL SURVEY

QUESTION	MEAN	MODE	MEDIAN
1	1.6	2	2
2	1	1	1
3	1.5	2	1
4	2.6	3	3
5	3	3	3
6	3	3	4
7	2.9	3	3
8	2.1	2	2
9	2.8	3	3
10	2.7	2	2
11	1.8	2	2
12	3.4	4	4
13	2.6	3	3
14	2.1	2	2
15	2.8	3	3

Data for this table follows.

Question	1	2	3	4	Total
1	35	44			79
2	77	2			79
3	40	31	4	1	76
4	8	27	31	10	76
5	5	16	39	17	77
6	5	18	24	10	76
7	4	23	40	10	77
8	20	34	10	7	71
9	3	24	41	8	76
10	5	34	30	8	72
11	28	37	6	3	74
12	3	10	16	47	76
13	9	25	29	13	76
14	21	31	13	9	74
15	7	17	35	15	74

The first column represents the question number. The number in the next columns numbered 1 through 4 represent the numerical equivalent to the responses given for the questions. The final column represents the total number of valid responses.

APPENDIX F

MEAN/MODE/MEDIAN TABLES BY CLASS

Computer Science 330: Data Structure

QUESTION	MEAN	MODE	MEDIAN
1	1.5	1.5	1.5
2	1	1	1
3	2	2	2
4	3.1	3	3
5	3.9	3	3
6	3.6	4	4
7	3	3	3
8	2.4	2	2
9	2.7	3	3
10	2.5	2.5	2.5
11	1.8	2	2
12	3.4	4	4
13	3	3	3
14	2.3	2	2
15	2.6	3	3

Data for this table follows.

Question	1	2	3	4	Totals
1	5	5			10
2	10	0			10
3	1	8	1	0	10
4	0	1	7	2	10
5	0	3	4	4	10
6	0	0	3	6	9
7	0	2	6	2	10
8	1	6	3	0	10
9	0	3	7	0	10
10	0	5	5	0	10
11	2	6	1	0	9
12	1	1	1	7	10
13	1	2	3	4	10
14	1	5	2	1	9
15	0	4	6	0	10

The first column represents the question number. The number in the next columns numbered 1 through 4 represent the numerical equivalent to the responses given for the questions. The final column represents the total number of valid responses.

Computer Science 401: Contemporary Computer Architecture

QUESTION	MEAN	MODE	MEDIAN
1	1	1	1
2	1	1	1
3	2.3	2.3	2
4	2.75	2	2.5
5	3	3	3
6	3	3	3
7	2	2	2
8	4	4	4
9	1.67	1	1
10	3	3	3
11	2.5	2.5	2.5
12	3	4	4
13	3.3	4	4
14	4	4	4
15	1.5	1.5	1.5

Data for this table follows.

Question	1	2	3	4	Total
1	4	0			4
2	4	0			4
3	1	1	0	1	3
4	0	2	1	1	4
5	0	1	2	1	4
6	0	1	2	1	4
7	2	0	2	0	4
8	0	0	0	2	2
9	2	0	1	0	3
10	0	1	1	1	3
11	1	0	0	1	2
12	1	0	0	2	3
13	0	1	0	2	3
14	0	0	0	2	2
15	1	1	0	0	2

The first column represents the question number. The number in the next columns numbered 1 through 4 represent the numerical equivalent to the responses given for the questions. The final column represents the total number of valid responses.

Computer Science 460: Operating Systems

QUESTION	MEAN	MODE	MEDIAN
1	1	1	1
2	1	1	1
3	1.4	1	1
4	2.5	2	2.5
5	2.6	3	3
6	3.3	3	3
7	2.6	3	3
8	2.1	2	2
9	2.7	3	3
10	2.3	2	2
11	1.7	2	2
12	3.6	4	4
13	2.7	3	3
14	2.1	2	2
15	3	3	3

Data for this table follows.

Question	1	2	3	4	Totals
1	26	0			26
2	26	0			26
3	15	11	0	0	26
4	3	10	9	4	26
5	2	6	13	5	26
6	2	6	19	8	26
7	2	8	14	2	26
8	8	11	2	4	25
9	1	8	14	3	26
10	2	14	9	1	26
11	11	12	2	1	26
12	0	3	5	18	26
13	3	7	11	5	26
14	6	13	5	2	26
15	1	5	12	8	26

The first column represents the question number. The number in the next columns numbered 1 through 4 represent the numerical equivalent to the responses given for the questions. The final column represents the total number of valid responses.

Computer Science 620: Programming Languages

QUESTION	MEAN	MODE	MEDIAN
1	2	2	2
2	1	1	1
3	1.7	1.5	2
4	2.5	3	3
5	3	3.5	3
6	2.9	2	3
7	2.5	3	3
8	1.9	2	2
9	2.5	2	2
10	2.7	2.5	3
11	1.8	2	2
12	3.1	3	4
13	2.3	2	2
14	2	2.5	2
15	2.3	2	2

Data for this table follows.

Question	1	2	3	4	Totals
1	0	9			9
2	9	0			9
3	4	4	1	0	9
4	1	3	4	1	9
5	1	1	3	3	8
6	0	4	2	3	9
7	0	4	5	0	9
8	2	5	1	0	8
9	0	5	3	1	9
10	0	4	4	1	9
11	3	5	1	0	9
12	0	3	2	4	9
13	1	5	2	1	9
14	3	3	3	0	9
15	0	6	3	0	9

The first column represents the question number. The number in the columns numbered 1 through 4 represent the numerical equivalent to the responses given for the to questions. The final column represents the total number of valid responses.

Computer Science 630: Theory of Algorithms

QUESTION	MEAN	MODE	MEDIAN
1	2	2	2
2	1.3	1	1
3	2	1	1.5
4	2	2	2
5	2.8	3	3
6	2.8	4	3
7	3	3	3
8	2.3	3	2.5
9	3	3	3
10	2.3	1	2
11	2	2	2
12	3.8	4	4
13	2.5	3	3
14	2.3	1	2
15	2.7	2.7	3

Data for this table follows.

Question	1	2	3	4	Totals
1	6	0			6
2	4	2			6
3	2	1	0	1	4
4	1	2	1	0	4
5	0	1	3	0	4
6	1	1	0	2	4
7	0	1	2	1	4
8	1	1	2	0	4
9	0	1	2	1	4
10	2	0	1	1	4
11	1	2	1	0	4
12	0	0	1	3	4
13	1	0	3	0	4
14	2	0	1	1	4
15	1	0	1	1	3

The first column represents the question number. The number in the next columns numbered 1 through 4 represent the numerical equivalent to the responses given for the questions. The final column represents the total number of valid responses.

Computer Science 660: Operating Systems Concepts

QUESTION	MEAN	MODE	MEDIAN
1	2	2	2
2	1	1	1
3	1.3	1	1
4	2	2.5	2
5	2.9	3	3
6	3.5	4	3
7	2.9	3	3
8	1.9	2	2
9	2.8	2.5	3
10	2.8	2.5	3
11	1.7	2	2
12	3.3	4	4
13	2.4	2.5	2
14	2	2	2
15	2.9	3	3

Data for this table follows.

Question	1	2	3	3	Totals
1	0	24			24
2	24	0			24
3	18	5	1	0	24
4	3	9	9	2	23
5	2	4	13	5	24
6	2	6	7	9	24
7	0	8	11	5	24
8	8	11	3	1	23
9	0	7	14	3	24
10	1	10	10	3	24
11	10	12	1	1	24
12	1	3	7	13	24
13	3	10	10	1	24
14	9	10	2	3	24
15	4	1	13	6	24

The first column represents the question number. The next number in the next columns numbered 1 through 4 represent the numerical equivalent to the responses given for the questions. The final column represents the total number of valid responses.

APPENDIX G

INITIAL APPROVAL LETTER

CALIFORNIA STATE UNIVERSITY
SAN BERNARDINO

5500 University Parkway, San Bernardino, CA 92407-2397

February 20, 2004

CSUSB INSTITUTIONAL REVIEW BOARD
Exempt Review
IRB# 03083
Status
APPROVED

Ms. Cynthia P. Farquhar
c/o: Prof. Richard Botting
Department of Computer Science
California State University
5500 University Parkway
San Bernardino, California 92407

Dear Ms. Farquhar:

Your application to use human subjects, titled, "An Empirical Study: Usage of UML in the BS and MS Degree Programs at CSUSB" has been reviewed and approved by the Institutional Review Board (IRB) of California State University, San Bernardino.

- This protocol is approved as exempt if conducted exactly as described in the protocol. There is a discrepancy between the protocol (a survey instrument) and the methodology in the thesis proposal ("interviews with students," "interviews with faculty").

You are required to notify the IRB if any substantive changes are made in your research prospectus/protocol, if any unanticipated adverse events are experienced by subjects during your research, and when your project has ended. If your project lasts longer than one year, you (the investigator/researcher) are required to notify the IRB by email or correspondence of *Notice of Project Ending* or *Request for Continuation* at the end of each year. Failure to notify the IRB of the above may result in disciplinary action. You are required to keep copies of the informed consent forms and data for at least three years.

If you have any questions regarding the IRB decision, please contact Michael Gillespie, IRB Secretary. Mr. Gillespie can be reached by phone at (909) 880-5027, by fax at (909) 880-7028, or by email at mgillesp@csusb.edu. Please include your application identification number (above) in all correspondence.

Best of luck with your research.

Sincerely,

Joseph Lovett

Joseph Lovett, Chair
Institutional Review Board

JL/mg

cc: Prof. Richard Botting, Department of Computer Science

The California State University
Bakersfield • Channel Islands • Chico • Dominguez Hills • Fresno • Fullerton • Hayward • Humboldt • Long Beach • Los Angeles • Maritime Academy Monterey Bay • Northridge • Pomona • Sacramento • San Bernardino • San Diego • San Francisco • San Jose • San Luis Obispo • San Marcos • Sonoma • Stanislaus

APPENDIX H

PROTOCOL CHANGE APPROVAL

CALIFORNIA STATE UNIVERSITY
SAN BERNARDINO

5500 University Parkway, San Bernardino, CA 92407-2397

May 14, 2004

CSUSB INSTITUTIONAL REVIEW BOARD
Protocol Change
IRB# 03083
Status
APPROVED

Ms. Cynthia P. Farquhar
c/o: Prof. Richard Botting
Department of Computer Science
California State University
5500 University Parkway
San Bernardino, California 92407

Dear Ms. Farquhar:

Your protocol change in your application to use human subjects, titled, "An Empirical Study: Usage of UML in the BS and MS Degree Programs at CSUSB" has been reviewed and approved by the Chair of the Institutional Review Board (IRB). A change in your informed consent requires resubmission of your protocol as amended.

You are required to notify the IRB if any future substantive changes are made in your research prospectus/protocol, if any unanticipated adverse events are experienced by subjects during your research, and when your project has ended. If your project lasts longer than one year, you (the investigator/researcher) are required to notify the IRB by email or correspondence of *Notice of Project Ending* or *Request for Continuation* at the end of each year. Failure to notify the IRB of the above may result in disciplinary action. You are required to keep copies of the informed consent forms and data for at least three years.

If you have any questions regarding the IRB decision, please contact Michael Gillespie, IRB Secretary. Mr. Gillespie can be reached by phone at (909) 880-5027, by fax at (909) 880-7028, or by email at mgillesp@csusb.edu. Please include your application identification number (above) in all correspondence.

Best of luck with your research.

Sincerely, Joseph Lovett by mr

Joseph Lovett, Chair
Institutional Review Board

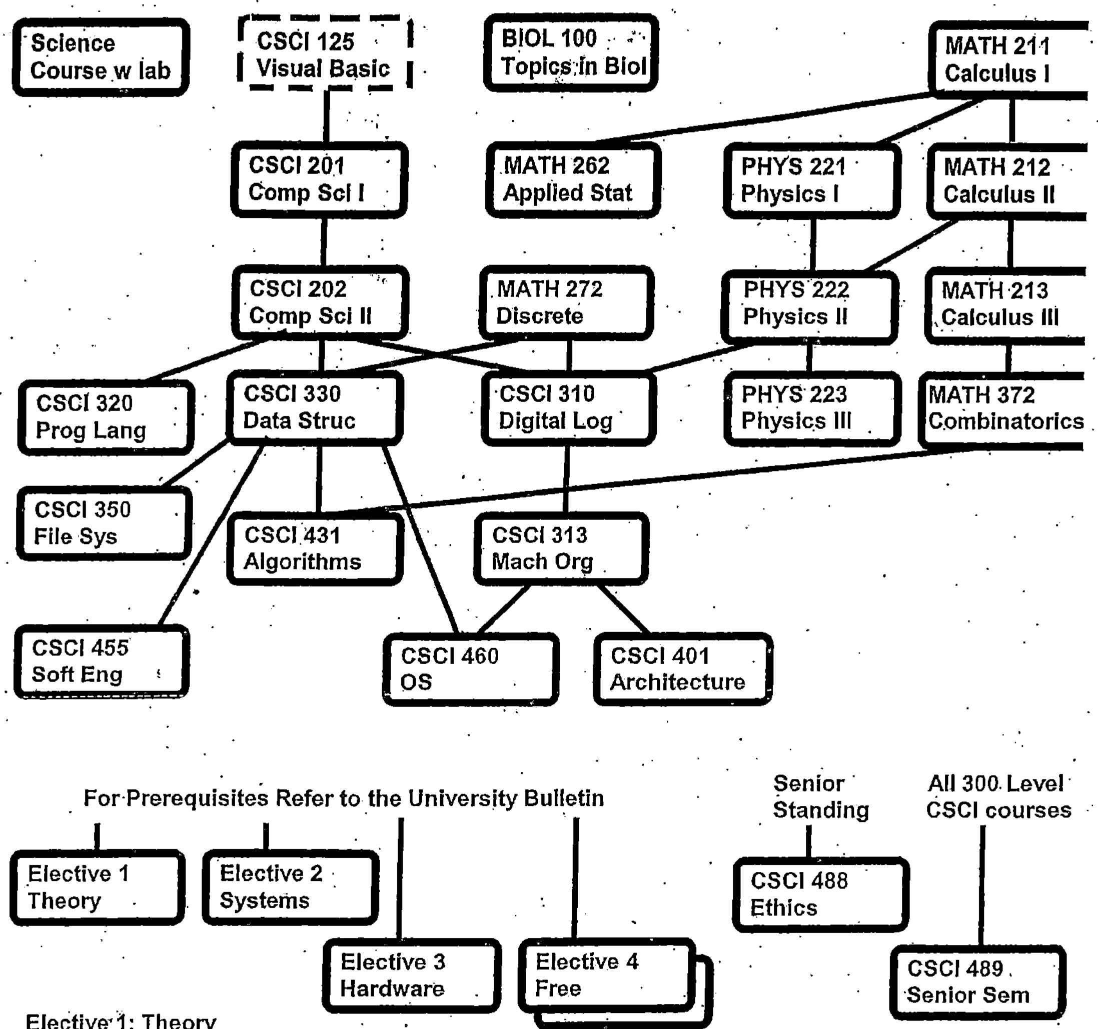
JL/mg

cc: Prof. Richard Botting, Department of Computer Science

APPENDIX I

BACHELOR OF SCIENCE DEGREE IN COMPUTER SCIENCE CURRICULUM FLOW CHART

BS Degree in Computer Science Curriculum
Flow Chart

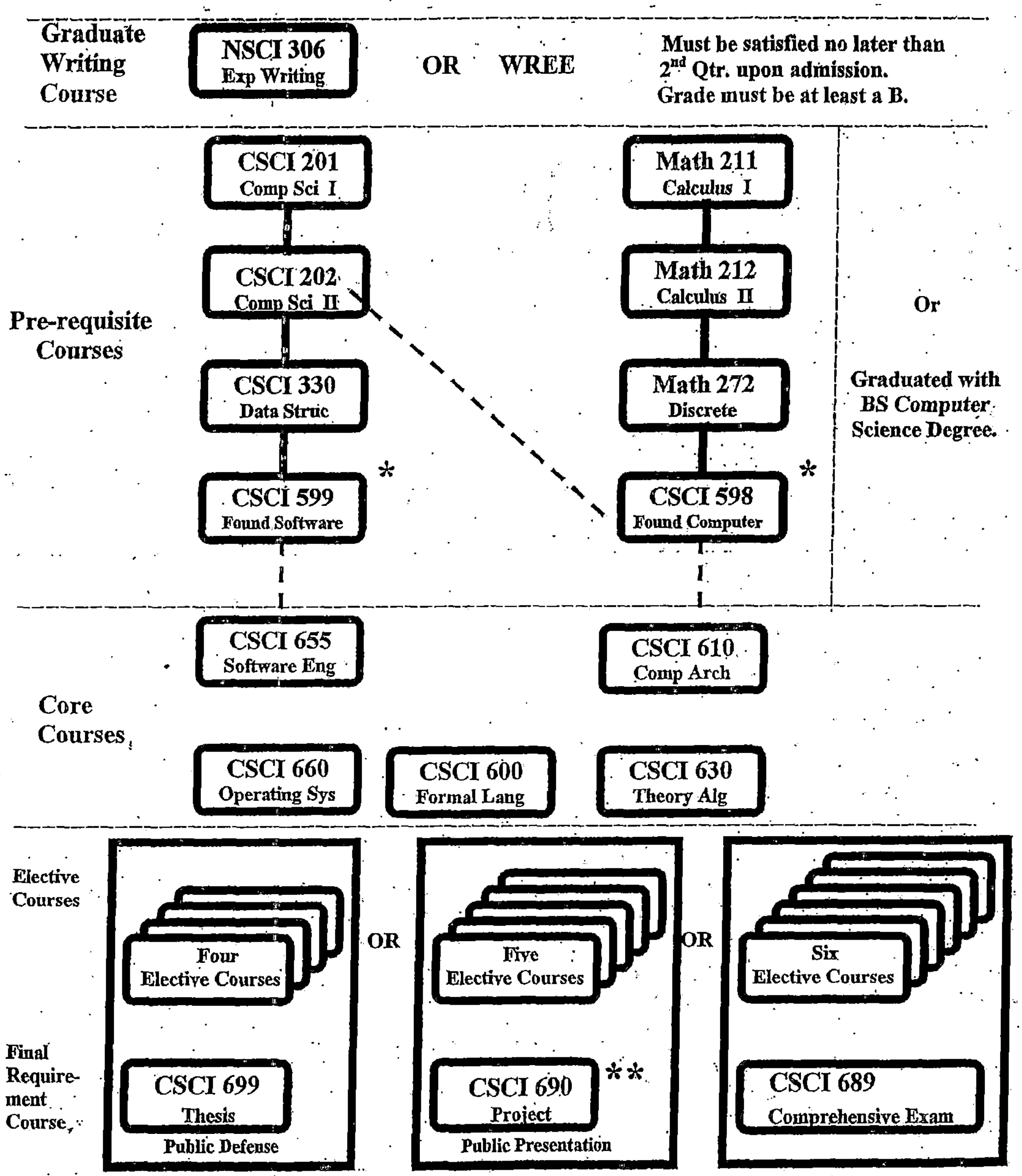


Elective 1: Theory
Choose 4 Units from CSCI 500, 511, 512, 515 or 546
Elective 2: Systems
Choose 4 Units from CSCI 540, 565, 570, 572, or 580
Elective 3: Hardware
Choose 4 Units from CSCI 510, 524, 525, 530, or 531
Elective 4: Free
Choose 8 Units from 400 – and above level courses in CSCI not previously counted as elective above

APPENDIX J

MASTER OF SCIENCE CURRICULUM FLOW CHART

MS Curriculum Flow Chart



* May be counted as Electives
** Passing of Oral Comprehensive Examination on Core Courses before Advancement to Candidacy

Updated July 13, 2004

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